Communications Theory (Lecture 1) – Introduction

Plan (75 min. class)

* Go through class outline ⇒ 10 min
* Outline of a communication system (Block diagram) ⇒ 30 min
* Communication channels and their characteristics (20)
* Mathematical model of the communication channel (15)

Block diagram of a communication system (1.2)

Information Source & Input Transducer → Transmitter → Channel → Receiver → Output Transducer → Output Signal

* Purpose of communication system is to send messages generated at a source to one or more destinations
* Information generated by the source is usually in a form that is not suitable for direct transmission. For example, it may be acoustic sound (voice, music...), or image, or textual message or many other forms of information.
* Information generated by the source needs to be converted to electrical signal ⇒ done by some form of transducers. Examples: Microphone, digital camera, keyboard...

The basic electronic communication system consists of three parts

1) Transmitter
2) Channel
3) Receiver

Transmitter - converts the electrical signal into a form that is suitable for transmission through the physical channel or transmission medium.

a. Coupling of message signal to the transmission medium is usually accomplished through modulation process
Depending on the input signal, the transmitter modifies some properties of a sinusoidal waveform, usually referred to as the carrier. Through the modulation process, the transmitter may modify either amplitude, frequency, phase, or any combination of the three.

* Modulation allows:
  - Efficient transmission through the communication channels.
  - Use of the same channel by multiple users.

The Channel: Communication channel - physical medium that is used to send the signal from transmitter to receiver. There are several types of channels:

- Wireline (twisted pair, coax)
- Optical (Optical Fiber)
- Wireless
- Radio frequency
- Acoustic

* Cloning: duplicates the signal
* Distortion can be:
  1) Adverse (usually characterized as random processes)
  2) Non-adverse

Adverse: thermal noise, out-of-system interference, jamming
Non-adverse: channel can often be seen as a linear filter (possibly time varying). In general, process of filtering changes properties of the signal.

The Receiver: The purpose of the receiver is to recover original signal that was passed to the transmitter. Recovery of the signal usually involves processes of signal demodulation. Since signal suffers various kinds of disturbances, the receiver needs to be design to perform additional hostile of noise filtering, interference reduction, channel equalizing, etc.
Finally, at the end of communication system, transducer converts the received electrical signal into a form that can be presented to the final user. Typical examples of transducers are speakers, image presentation devices, computer screens, etc.

1.4) Mathematical model of communication channels.

* Different physical channels have different mathematical model.
* There are three basic channel models that we will consider in this course.

1) The additive noise channel
   2) Linear time-invariant filters channel
   3) Linear time-variant filters channels

1) The additive noise channel

\[ r(t) = a \cdot s(t) + n(t) \]

Channel introduces two forms of distortion:

1) Attenuation
2) Additive noise
In the special case when the noise is Gaussian, the channel is called Additive White Gaussian Noise (AWGN) Channel.

2) Linear time-invariant filter channel.

\[ r(t) = h(t) \ast s(t) + n(t) \]

* Important: It is assumed that the impulse response of the channel is constant over the communication period.*

\[ h(t) - \text{impulse response of the channel} \]

Symbol * indicates convolution, that is

\[ r(t) = \int_{-\infty}^{\infty} \delta(t - \tau) s(\tau) d\tau + n(t) = \int_{-\infty}^{\infty} s(\tau) h(t - \tau) d\tau + n(t) \]

Channel introduces following distortions:

1) Amplitude of the signal is changed \( y \Rightarrow x \) the time domain representation of the signal changes shape
2) Phase of the signal is changed \( y \Rightarrow x \) the signal changes shape
3) Additive noise

3) Linear time-varying filter channel.
The impulse response of the channel changes through time:

\[ r(t) = \sum_{l \geq 0} h(t-l) + n(t) \]

\[ = \int_{-\infty}^{+\infty} h(t, \tau) s(t-\tau) d\tau + n(t) \]

**Example 1:** A classical example of time-invariant filter channel is a wireline-guided wave channel.

Frequency response of a wireline-guided wave channel:

- \( f_c \) - cut-off frequency

- \( f_c \approx 100 \text{kHz} \) for twisted pair (depends on the length)
- \( f_c \approx 100 \text{MHz} \) for coaxial cable (depends on the width)
- \( f_c \approx 100 \text{GHz} \) for guided waves.

**Example 2:** An example of a time-varying channel is wireless wideband mobile channel.

\[ h(t) = \sum_{k=1}^{L} \alpha_k s(t-T_k) \]

Impulse response of the wireless communication channel.
In general, we may encounter some other types of channels:

1) Non-linear time-invariant channels
2) Non-linear time-variant channels

Theoretical analysis of these channels is usually more difficult. Usually, it is not carried through a general framework, but it is considered on a case-by-case basis.